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THE WORK OF AN ENGLISH MATHEMATICAL STUDENT.

By H. Bateman.

A few weeks ago Professor Babb invited me to give you a short address on some topic connected with the study of mathematics at English schools and universities. In thinking over the subject I have naturally tried to recall the various impressions I received during my school and college days, leaving out, of course, the marks of the cane. For a little while it has seemed just as if time had been put back ten years or so, that I was again looking at things from the point of view of the student and comparing experiences and opinions with my college friends.

My school experience has not been sufficient to enable me to give you a representative account of the methods of teaching adopted at the different public schools and of the amount of preparation which the boys received, because circumstances made it necessary for me to attend one school at a time.

What little information I have to give you, then, apart from my own observations, has been derived from conversations with friends or from more reliable sources, such as periodicals and addresses given by prominent men.

At a school like St. Paul's, London, or Manchester Grammar School, mathematics is studied both as a routine subject and as a specialty. The student who specializes in mathematics does so principally with the object of gaining a scholarship at one of the universities; he must consequently acquire considerable facility in solving problems and in being able to reproduce book-work quickly and accurately.

The plan which is adopted at some schools is to leave the student practically to himself except for occasional help from the master in the solution of a difficult problem. Very few lectures of an advanced character are given, partly because the master's time is occupied with elementary work and partly because the few students who are specializing in mathematics are at different levels, both as regards knowledge and ability. At other schools regular courses may be given; for instance, I was told of one school where a master gave an excellent course on dynamics, illustrating the theory by means of simple experiments.

Generally when a boy gains a scholarship at Oxford or Cambridge he has a fair knowledge of synthetic and analytical geometry, higher algebra, including the theory of equations, higher trigonometry, elementary differential calculus and mechanics.

Of course, I don't want you to infer from this that the different students who go up to Oxford and Cambridge have all received about the same amount of preparation. The mathematical equipment of a Cambridge freshman is a quantity which varies over a very wide range. Under the old regime the tuition a student received would depend entirely upon the amount of preparation he had received and the impression he had given of his ability. If he was well equipped he was advised to attend lectures of an advanced nature straightaway; these might consist of analytical statics and differential equations in his first term, with elliptic functions and particle dynamics in his second term. He thus spent his first two years preparing for what used to be the second four days of the tripos examination.

At the smaller colleges it is different, and generally a man will spend his first year preparing for the first four days of the examination. This plan is probably still followed now that the two parts of the examination are taken in different years and are slightly different in character from what they were previously.

A boy who is trying for a scholarship at one of the modern English universities like Manchester, Liverpool or Birmingham will not require such an extensive knowledge of mathematics, and will generally leave school a little earlier than if he were going to Oxford or Cambridge. In the scholarship examination the subjects are geometry, the substance of Euclid I.–IV. and VI.; algebra as far as the binomial theorem inclusive; plane trigonometry to the solution of triangles; elementary analytical geometry; the conic sections. Credit is given to candidates for their knowledge of classics: elements of English language, literature and history, French and German.

In his first year at the university the student attends courses on subjects not belonging to his specialty, so as to get a good general education, but later on he specializes entirely.

At Cambridge the plan is different. An honor man who is reading for the tripos is recommended to devote all his time to his special subject; in fact, the mathematical student has so much work to get through that it is almost necessary for him to coach both in term time and during the part of the long vacation which he spends at college.

I might say a few words here about the general effect of the coaching system.

The students used to vie with one another to see who could produce the prettiest solution of a given problem. The geometrical questions usually provided most scope for originality and on one occasion a student showed up a geometrical solution of a difficult analytical problem which was obviously meant to be done analytically. The coach gazed at it and said: "Oh! I am sure I couldn't have done that."

One influence which the Cambridge training has upon mathematical students is to develop the artistic faculty; a good man will not be satisfied with any old solution of a problem and when he has got one solution he will try to simplify it and present it in as clear a form as possible.

It used to be very amusing to see the look of pain that would come on the coach's face when a man showed up a six-page solution of a problem which could be solved very easily in two pages. Mind you, credit was always given to a student who obtained a solution of a difficult problem, whether the solution was pleasing or not, but brevity received due encouragement.

E. J. Routh, the man who beat Clerk Maxwell in the tripos examination, is perhaps the best known of the Cambridge coaches, and his method of teaching may be regarded as typical. The following description of Routh's method of teaching is taken from Forsyth's obituary notice of him in the *Proceedings of the London Mathematical Society*.*

The pupils went to him three times a week, for an hour on each occasion. They were arranged in classes of six to ten, selected at first mainly by their own statements of mathematical knowledge brought from school, and sifted later by their attainments and progress. Each hour's work was substantially of the nature of a lecture. A few minutes at the beginning of the hour were devoted to the inspection of written exercises, a process at which Routh was wonderfully quick. The remainder of the hour was occupied with a skilful exposition of the subject under consideration, sometimes summarized in such a way as almost to compel remembrance.

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* Ser. 2, Vol. 5 (1907).

In addition to the direct teaching, he sent to all his pupils a weekly paper of a dozen problems, taken mainly from past examinations. The conditions of answering this paper were made to alternate in successive weeks. In one week a student could devote unlimited time to the questions; in the other he was expected to limit himself to three hours so as to feign some similarity to the pressure of the Senate House. The pupils' answers were deposited in Routh's rooms in Peterhouse on the Friday or the Saturday of any week; they were returned on the succeeding Monday, when he placed in an outer room a carefully written set of solutions.

To add a stimulus of competition, every pupil's answers had been marked, and there was a list containing names and marks, so that the men even of different years were almost encouraged to regard the weekly problem paper as a field for rivalry and comparison.

Finally, at some period before the crucial examination, there began the process of revision, in the form of bookwork papers. The answers to each such paper had to be brought two days after the paper was set, and they were examined critically in class. The pupils were brought up to the mark, so far as the teacher was concerned, partly by good humor, partly by occasional warnings that were kindly in phrase and in spirit, and always under a genial sense of his easy mastery over the whole range of subjects included in the examination.

It is obvious that this process, if not supplemented by other means, would imply a uniformity of treatment which would not be found advantageous by the eager members of even an average class. The necessary supplement was provided by Routh in the form of "manuscripts," which really were of the character of small pamphlets dealing with special portions of subjects not taught in classes. Pupils were expected to copy these manuscripts, in default of English text-books; but diligence in taking copies was far from universal.

The coaching system is probably despised by some of the continental mathematicians and I remember an amusing story about a foreigner who came to lecture in Cambridge on chemistry. He wanted to impress upon the student that he was going to interest them in research work and not to coach them up for an examination, so he said: "I want you to understand that I am not a coachman."

The subjects for the first part of the mathematical tripos under the old regulations were:

Pure geometry, including geometrical conics.
Newton's Principia.
Algebra and trigonometry.
Analytical geometry, including some of the elementary properties of higher plane curves. Solid geometry, including elementary differential geometry.
Differential and integral calculus.
Elementary statics and dynamics.
Analytical statics and attractions.
Particle and rigid dynamics.
Optics and astronomy.
Electricity and magnetism.
Hydrostatics and heat.
Hydrodynamics and sound.
Differential equations, elliptic functions, Fourier's theorem, spherical harmonics, Bessel's functions, calculus of variations.

Under the new regulations an examination in the elementary subjects can be taken at the end of the second term. This examination is now called Part I. Part II. comprises subjects in schedules A and B. Schedule A contains the ordinary subjects to be taken by all candidates, the B subjects being taken only by men who are candidates for a mark of distinction. Part II. cannot be taken earlier than in the eighth term;* it corresponds more or less to the second four days of the old examination, but a candidate has the option of specifying the range of subjects B in which he desires to be examined. The order of merit has now been abolished and the names of the successful candidates for honors are arranged in three classes: wranglers, senior optimes and junior optimes, the names in each being in alphabetical order. A distinctive mark is attached to the name of a man who has done fairly well in schedule *B*, and a different mark if he deserves special credit for his answers to *B*.

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* See *Nature,* January 17, 1907, or the Cambridge Univ. Calendar.

Under the old system a man generally spent three years in preparing for his tripos, but occasionally a man who had graduated at some other university would take the examination at the end of two years. I can remember how astonished we all were when Eddington did this and came out at the head of the list; after this feat had been performed once it was repeated more than once.

The old Part II. of the mathematical tripos has now been abolished and students are left to study the higher branches of mathematics without being bothered with preparation for an examination.

A student at a university like Manchester and Liverpool will not cover quite so much ground as one at Cambridge, but he will nevertheless receive a good training in both pure and applied mathematics; astronomy is generally omitted from the list of subjects. In some cases a course of lectures will be given on some subject like the theory of functions or the theory of probability, which will give the students a glimpse of some of the developments which are taking place in the mathematical world.

I am not very well acquainted with the teaching of mathematics at Oxford University. As far as I know the examination system is very similar to the one now adopted at Cambridge; there is an examination called Moderation, which is taken in the first or second year, and a final examination, which is taken in the third year. As regards the work done in pure mathematics, considerable attention seems to be paid to geometry and the algebra of quantics. The principal laurels to be won by a mathematical student at Oxford are the junior mathematical scholarship, the senior mathematical scholarship and a fellowship.

With regard to the present state of school teaching* in mathematics, I know very little. You will remember that about ten years ago a movement in the direction of reform in mathematical teaching was set on foot by Professor Perry and others. The abolition of Euclid as the sole authority in geometry and the stress laid upon graphical methods have been direct consequences of the agitation, and the changes in the mathematical tripos at Cambridge are also partly due to it. The aim of the movement* has been the very practical one of making the mathematical teaching more suitable for the training of engineers and students of natural science, and also to relieve the English secondary school teachers from the burden of a too precise examination system, imposed by the great examining bodies.

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* Some useful information on the teaching of mathematics in the United Kingdom may be derived from the eight reports recently issued by the Board of Education and published by Wyman. The reports issued by the Mathematical Association should also be consulted.

It will be interesting to make a survey in a few years' time to see how the character of English mathematical work has been affected by these changes.

The attitude of some of the teachers towards the new methods is indicated in some of the discussions and addresses given at meetings of the Mathematical Association,† and also in a discussion which took place at a meeting of the Manchester Mathematical Society, in 1908. At this meeting Professor Leahy read a paper on the desirability of a definite order of propositions in geometry. He thought that a definite order differing very little from those adopted in the new text-books could easily be decided upon and would be welcomed by most teachers and students. He was supported by the majority of the members present; but some thought that so many improvements had been made in recent years that if a definite order were introduced at the present time progress would be retarded.

BRYN MAWR, PA.

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* A good account of this movement with references is given in Prof. E. H. Moore's presidential address to the American Mathematical Society. *Bull. Amer. Math. Soc.*, Vol. 9, 1902–3.

† *Mathematical Gazette*, Jan., March, Dec., 1909, March, July, 1910, March, 1911.